Asian Journal of Applied Science and Technology (AJAST)
Volume 7, Issue 1, Pages 80-104, January-March 2023

Sustainability of Pod Yields of Groundnut through Crop Seasonal Rainfall, Length of Growing Period and Cultivated Area under Arid Alfisols of Anantapur in South India

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DOI: https://doi.org/10.38177/ajast.2023.7108

Article Received: 21 January 2023 *Article Accepted: 28 February 2023* *Article Published: 15 March 2023*

ABSTRACT

A study was conducted with the objective of assessing the effect of crop seasonal rainfall and length of growing period on the sustainability of pod yields of groundnut attained in 31 mandals under arid Alfisols of Anantapur in Andhra Pradesh. We have considered the variability of mandals with regard to (i) crop seasonal rainfall (mm) and (ii) pod yield of groundnut (kg/ha) during 2001 to 2020; (iii) extent of crop area (ha) during 2009 to 2020; and (iv) length of growing period (days). Based on the mean and standard deviation (SD) of each parameter, the mandals were classified into 5 groups viz., (i) G1: Less than (Mean–2SD); (ii) G2: (Mean–2SD) to (Mean–SD); (iii) G3: (Mean–SD) to (Mean+SD); (iv) G4: (Mean+SD) to (Mean+2SD); and (v) G5: More than (Mean+2SD). Out of 31 mandals, 22 mandals for area and crop seasonal rainfall, 20 mandals for LGP and 18 mandals for yield have fallen in G3. Estimates of correlation were derived between groundnut area, crop seasonal rainfall and yield for each mandal over years and tested for significance to assess the superiority of mandals. Significant correlation of yield and crop seasonal rainfall was observed which ranged from 0.433 at Kalyandurg to 0.765 at Putlur. Similarly, significant correlation between yield and area of groundnut was observed in Kalyandurg (-0.764), Brahmasamudram (-0.674) and Rapthadu (-0.584) mandals. The predictability of yield and prediction error were derived based on a regression model of yield calibrated through the crop seasonal rainfall, LGP and crop area in different mandals. The model gave significant predictability (R^2) value of 0.46 with prediction error of 90.9 kg/ha and indicated negative effect of area, positive effect of crop seasonal rainfall and LGP on yield. The sustainability yield index ranged from 26.6% (Kambadur) to 87.5% (Peddavadagur) with mean of 53.9% (CV of 30.1%) over years. Ranks were assigned to the mean and variation of area, crop seasonal rainfall, yield, LGP and SYI of each mandal and rank sums were derived. Guntakal, Gooty and Vidapanakal were superior with rank sums of 30, 38 and 70 respectively. Guntakal was superior with an area of 16570 ha (CV of 17.3%), crop seasonal rainfall of 436.1 mm (CV of 33.4%), LGP of 140 days, yield of 644 kg/ha (CV of 70.9%) and SYI of 76.5%, while Gooty was superior with area of 14146 ha (CV of 14.6%), crop seasonal rainfall of 429.6 mm (CV of 42.4%), LGP of 140 days, yield of 663 kg/ha (CV of 69.1%) and SYI of 79.1%. Similarly, Vidapanakal was superior with area of 5077 ha (CV of 31.1%), crop seasonal rainfall of 403.2 mm (CV of 47.4%), LGP of 140 days, yield of 654 kg/ha (CV of 49.5%) and SYI of 77.9%. Due to maximum LGP and crop seasonal rainfall, we recommend that the farmers of these mandals could enhance the area of groundnut and attain maximum sustainable yields under arid Alfisols.

Keywords: Crop seasonal rainfall; Length of growing period; Crop area, Regression; Coefficient of variation; Sustainability yield index; Rank sum.

1. Introduction

Drought is one of the common problems occurring in rainfed agriculture. In India, about 69% of total sown area is susceptible to drought at one point of time or the other. Wilhite (2000) expressed that drought is the most common natural disaster occurring in any climatic region in the world. About 20-25% districts in India suffer from droughts of varying intensities every year (Sinha, 2001). In a paper by Rao et al., (2011), the authors have described about the long-term rainfall effects by analyzing the trends at both micro and macro-level in Andhra Pradesh. The crop yields would get drastically reduced with either lower crop seasonal rainfall or high intense rainfall during the different crop growth stages. In order to efficiently manage the drought under different climatic conditions, Sinha Anil (2001) has discussed about some useful strategies for disaster management in different regions in India.

Andhra Pradesh is 8th largest state in terms of geographical area (16 million ha), 10th in population (49.67 million), and ranks 3rd among drought prone states in India. Out of 40 lakh ha of rainfed area, about 45% area is in scarce zone of Andhra Pradesh with mean annual rainfall of 546 mm at Anantapur and 630 mm at Kurnool. About 25% of rainfed area of Andhra Pradesh is in Anantapur which is the rain shadow area with 2nd lowest precipitation after Jaisalmar in Rajasthan. The rainfall received in Anantapur is just sufficient to take up a crop with 15-18 weeks duration. A little variation in annual rainfall would adversely affect the prospects of rainfed crops. During last 18

years, Anantapur experienced 15 years of drought and 3 years of normal rainfall. Accordingly, 90% of cultivated land (about 11 lakh ha) would depend on rain for irrigation, while 70% of population depend on farming for livelihood. Out of total area of 19 lakh ha in Anantapur, 10 lakh ha is rainfed, while one lakh ha is irrigated through undependable tube wells and tanks.

Anantapur has maximum area of 82% under Alfisols and remaining 18% area under Vertisols. Anantapur has 31 mandals with arid Alfisols and Vertisols. Groundnut is one of the important crops grown by farmers in 31 mandals under Alfisols but mainly as a rainfed crop. During 2009-18, groundnut was grown in 589907 ha area under 31 mandals in the district. Farmers attain low yield due to constraints like low and erratic rainfall, low soil fertility, lack of suitable variety for attaining high yield, lack of suitable implements for agricultural operations, high cost of cultivation, lack of sufficient groundwater or any other source for supplemental irrigation during stress of crops, apart from labour and other problems.

There is a need of assessment of mandals for superiority for enhancing the area of groundnut for sustaining pod yields by considering the distribution of rainfall during the crop growing season, length of growing period, apart from the area of groundnut in each mandal. Efficient grouping of mandals could be made for planning different resources, enhancing or decreasing the groundnut crop area, apart from sustaining pod yields to a maximum extent. The relationships among these parameters would help in developing a suitable regression model for predicting the groundnut pod yield and assessing its sustainability based on a sustainability yield index as discussed by Maruthi Sankar et al., (2013a, 2013b). In spite of many constraints, farmers grow groundnut and do not attain profitable yield. An assessment is made in this paper by considering some resources of mandals viz., crop seasonal rainfall, area of groundnut, length of growing period, levels of yield attained by farmers during 2001 to 2020. Superior mandals are identified for expanding groundnut area for enhancing the production of groundnut with better rainwater use efficiency and making the crop more profitable.

2. Materials and Methods

2.1. Study details of mandals

A study has been conducted to assess the suitability of 31 mandals of Anantapur district for sustaining the pod yields of groundnut by considering the observations recorded in each mandal on (i) crop seasonal rainfall (CRF, mm); (ii) length of growing period (LGP, days), (iii) groundnut area (ha) and (iv) pod yield (kg/ha) during 2001 to 2020. Anantapur is located at latitude of 14° 40' 54.8" North, longitude of 77° 36' 2.13" East and altitude of 348.9 meters above the mean sea level. About 82% of soils in the district are Alfisols, while 18% of soils are Vertisols. Groundnut is the leading crop grown in Alfisols under all the mandals. Farmers have been growing groundnut in spite of erratic rainfall condition, low length of growing period, low yield and monetary returns and other constraints. The district has a normal annual rainfall of 525 mm received during 21st to 43rd standard meteorological week (SMW) in different mandals. Out of 31 mandals, 11 mandals have a rainfall in the range of 410.4 mm (Kudair mandal) to 498.6 mm (D Hirehal mandal), while 20 mandals have a rainfall in the range of 501.5 mm (Peddavadugur mandal) to 624.5 mm (Tadipatri mandal). The different mandals in the district have 4 length of growing periods (LGP) viz., (i) less than 90 days; (ii) 90-120 days; (iii) 120-150 days; and (iv) more than 150 days.

A detailed assessment of variability is made in this paper by considering the observations recorded during 2001 to 2020, and inferences drawn with regard to the sustainability of pod yields of groundnut and expansion of groundnut area in different mandals in Anantapur district.

2.2. Soil fertility status in different mandals

The soil pH in different mandals in Anantapur district ranged from 6.3-9.2 with mean of 7.9 (CV of 7.6%). Based on the soil texture, 34 mandals have sandy loam (SL) soils, followed by sandy clay loam (SCL) soils in 19 mandals, loamy sand (LS) soils in 6 mandals and clay loam (CL) soils in 4 mandals. Based on the soil organic carbon (SOC), 31 mandals were medium, while 17 mandals with low and 15 mandals with high status. The soil N was low in 62 mandals and medium in one mandal, while 52 mandals were low and 11 mandals were medium for soil P. The soil K was medium in 46 mandals, while 15 mandals had high and 2 mandals had low K.

2.3. Grouping of mandals based on mean and standard deviation of parameters

The mandals have been assessed based on mean and coefficient of variation (CV, %), and relationships of different parameters observed during 2001 to 2020. The mandals were grouped into 5 groups for each parameter by considering the mean and standard deviation (SD) of mandals over years. The 5 groups were (i) G1: Less than (Mean – 2SD); (ii) G2: (Mean – 2SD) to (Mean – SD); (iii) G3: (Mean – SD) to (Mean + SD); (iv) G4: (Mean + SD) to (Mean + 2SD); and (v) G5: More than (Mean + 2SD). The differences between mean values of variables observed in each pair of groups are tested based on Student's t-test and variability of groups could be assessed (Gomez and Gomez, 1984). The Student's t-test could be given as,

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left(\frac{s_p^2}{n_1} + \frac{s_p^2}{n_2}\right)}} \qquad \text{Where,} \quad s_p^2 = \frac{n_1 - 1\ s_1^2 + n_2 - 1\ s_2^2}{n_1 + n_2 - 2}$$

In the two groups to be compared, s^2_1 is the standard deviation of mandals in the 1st group; s^2_2 is the standard deviation of mandals in the 2nd group; n_1 and n_2 are the number of mandals in the 1st and 2nd groups respectively. The standard error (SE) of the difference between means of two groups of mandals could be given as,

$$SE\ \bar{x}_1 - \bar{x}_2 = \sqrt{\left(\frac{s_p^2}{n_1} + \frac{s_p^2}{n_2}\right)}$$

2.4. Correlation and Regression analysis

Estimates of correlation between different parameters were derived and tested for assessing the variability of resources of mandals. Five regression models were calibrated to assess the effect of (i) crop seasonal rainfall (CRF) on yield; (ii) area of groundnut on yield; (iii) temporal changes in yield; (iv) temporal changes in groundnut area; and (v) temporal changes in the crop seasonal rainfall for assessing the relationships and variability of parameters, apart from predicting the pod yield over years (Draper and Smith, 1998). The regression models calibrated for the data are,

$$\text{Yield} = \alpha + \beta\ (\text{Years}) \qquad (1)$$

Area = α + β (Years) (2)

CRF = α + β (Years) (3)

Y = α + β (Area) (4)

Y = α + β (CRF) (5)

Here α is intercept; and β is the slope of years in models (1), (2) and (3); area in model (4) and crop seasonal rainfall in model (5). A regression model of yield (Y, kg/ha) is calibrated for each mandal as a function of (i) area (ha), (ii) length of growing period (days), and (iii) crop seasonal rainfall (mm) as described by Maruthi Sankar (1986). The regression model could be given as,

Y = α + β1 (Area) + β2 (LGP) + β3 (CRF) (6)

Here α is intercept; β1, β2 and β3 are regression coefficients of area, length of growing period and crop seasonal rainfall respectively. The usefulness of regression model could be assessed based on coefficient of determination (R^2) which is the proportion of variance in yield that could be explained through area, LGP and crop seasonal rainfall parameters. The R^2 indicates predictability of yield attained in any mandal using the regression model, which is tested based on Snedecor's F-test. An estimate of standard error of mean (SEM) of yield could be derived for assessing the sustainability of yield over years.

2.5. Sustainability yield index

The sustainability yield index (SYI) could be determined as discussed by Maruthi Sankar et al., (2014) as a ratio of (i) difference between mean yield (kg/ha) of a mandal and prediction error of yield (kg/ha) based on multivariate regression model (6) of yield calibrated through area, crop seasonal rainfall and length of growing period and (ii) maximum mean yield (Y_{max}) attained in any mandal during the study period. The SYI (%) could be given as

SYI = [[(Mean yield)–Prediction error based on regression model]/Y_{max}] * 100 (7)

The estimate of SYI (%) ranges from 0 to 100. Higher the SYI, better would be the performance of groundnut in any given mandal over years.

2.6. Selection of superior mandals

Ranks could be assigned to different mandals for the (i) mean values of crop seasonal rainfall, area and yield; (ii) LGP; (iii) CV (%) of crop seasonal rainfall, area and yield; and (iv) SYI over years. Rank sums could be derived for each mandal based on the ranks assigned to different parameters. Superior mandals with lower rank sums could be identified for bringing more area under cultivation of groundnut in Anantapur district.

3. Results and Discussion

Using observations collected on area (ha), crop seasonal rainfall (mm), length of growing period (LGP) and pod yield (kg/ha) of groundnut from 31 mandals of Anantapur district during 2001 to 2020, an assessment is made about groundnut yield and its variability, its relationship with crop seasonal rainfall, crop area and LGP; and sustainability of pod yield of groundnut in different mandals. The crop seasonal rainfall received in mandals from 23 to 41 SMW during 2001 to 2020 ranged from 61.4 to 1041.0 mm with mean of 364.1 mm (CV of 45.4%). The mandal-wise

mean crop seasonal rainfall over years ranged from 278.1 to 436.1 mm with mean of 364.1 mm (CV of 10.8%). The groundnut area (ha) in different mandals during 2009 to 2020 ranged from 2 to 32534 ha with mean of 9831 ha (CV of 67.9%). The mandal-wise mean area of groundnut over years ranged from 873 to 21345 ha with mean of 9831 ha (CV of 59.7%). The length of growing period (LGP) ranged from 56 to 161 days with mean of 102 days (CV of 25.5%). The groundnut pod yield attained in mandals during 2001 to 2020 ranged from 0 to 1993 kg/ha with mean of 481 kg/ha (CV of 79.5%). The mandal-wise mean yield ranged from 283 to 723 kg/ha with mean of 481 kg/ha (CV of 24.4%) over years. The descriptive statistics of crop seasonal rainfall (mm), length of growing period (days), area (ha) and pod yield (kg/ha) are given in Table 1.

Table 1. Descriptive statistics of crop seasonal rainfall, length of growing period, area and yield of groundnut of different mandals during 2001 to 2020

Mandals	CRF (mm)	LGP (days)	Area (ha)	Yield (kg/ha)
Anantapur	365.3	105	9485	398
Atmakur	335.2	63	12077	355
B.K.Samudram	389.6	98	6325	474
Beluguppa	338.3	98	10960	369
Bommanahal	349.8	70	2404	561
Bramhasamudram	315.8	56	13743	348
D.Hirehal	376.3	161	7407	481
Garladinne	379.9	105	4275	468
Gooty	429.6	140	14146	663
Gummagatta	278.1	112	13012	487
Guntakal	436.1	140	16570	644
Kalyandurg	408.1	112	21345	322
Kambadur	286.5	112	15672	283
Kanekal	369.4	112	10635	465
Kudair	335.1	56	15596	379
Kundurpi	333.8	84	14677	328
Narpala	405.9	105	6153	422
Pamidi	376.6	91	6165	508
Peddapappur	297.0	70	1324	638
Peddavadagur	391.6	140	4383	723

Putlur	389.2	98	1236	575
Rapthadu	372.1	105	15071	345
Rayadurg	332.8	77	15176	453
Settur	342.9	112	14790	344
Singanamala	333.1	98	8163	545
Tadipatri	413.0	98	873	604
Uravakonda	375.1	98	14600	479
Vajrakarur	368.8	77	18919	521
Vidapanakal	403.2	140	5077	654
Yadiki	386.1	133	2900	581
Yellanur	374.4	98	1609	488
Minimum	*278.1*	*56*	*873*	*283*
Maximum	*436.1*	*161*	*21345*	*723*
Mean	*364.1*	*102*	*9831*	*481*
SD	*39*	*26*	*5872*	*117*
CV (%)	*10.8*	*25.5*	*59.7*	*24.4*

3.1. Grouping of mandals based on the changes in area

Among different mandals, Tadipatri mandal was found to have the lowest mean area of 986 ha (CV of 135.5%), while Kalyandurg had the highest mean area of 23232 ha (CV of 28.4%) over years. Based on the grouping of mandals using mean and standard deviation (SD) of area over years, a maximum of 22 Mandals viz., Garladinne, Peddavadagur, Vidapanakal, Narpala, Pamidi, B.K.Samudram, D.Hirehal, Singanamala, Anantapur, Kanekal, Beluguppa, Atmakur, Gummagatta, Bramhasamudram, Gooty, Uravakonda, Kundurpi, Settur, Rapthadu, Rayadurg, Kudair, Kambadur had an area of groundnut falling in the G3 group of (Mean–SD) to (Mean+SD) group. These mandals had an area in the range of 4275 to 15672 ha with mean area of 10799 ha (CV of 38.1%). Six mandals viz., Tadipatri, Putlur, Peddapappur, Yellanur, Bommanahal and Yadiki have fallen in the G2 group of (Mean-2SD) to (Mean-SD) with range of 873 to 2900 ha with mean of 1724 ha (CV of 44.8%) over years. Three mandals viz., Guntakal, Vajrakarur and Kalyandurg have fallen in the G4 group of (Mean+SD) to (Mean+2SD) with area ranging from 16570 to 21345 ha with mean area of 18944 ha (CV of 12.6%). Gummagatta had a mean area of 13012 ha with lowest CV of 13.9%, while Putlur had a mean area of 1236 ha with highest CV of 145.9% over years. The descriptive statistics of groundnut area (ha) observed in different groups of mandals during 2009 to 2020 are given in Table 2.

Table 2. Descriptive statistics of groundnut area (ha) in different groups of mandals during 2009 to 2020

Group	Mandals	Minimum	Maximum	Mean	SD	CV
G1: Less than (Mean–2SD) (0 ha)	NIL					
G2: (Mean -2SD) to (Mean - SD) (0 to 3960 ha)	6 Mandals: Tadipatri, Putlur, Peddapappur, Yellanur, Bommanahal, Yadiki	873	2900	1724	772	44.8
G3: (Mean - SD) to (Mean + SD) (3961 to 15703 ha)	22 Mandals: Garladinne, Peddavadagur, Vidapanakal, Narpala, Pamidi, B.K.Samudram, D.Hirehal, Singanamala, Anantapur, Kanekal, Beluguppa, Atmakur, Gummagatta, Bramhasamudram, Gooty, Uravakonda, Kundurpi, Settur, Rapthadu, Rayadurg, Kudair, Kambadur	4275	15672	10799	4116	38.1
G4: (Mean + SD) to (Mean + 2SD) (15704 to 21574 ha)	3 Mandals: Guntakal, Vajrakarur, Kalyandurg	16570	21345	18944	2388	12.6
G5: More than (Mean + 2SD) (>21575 ha)	NIL					
Overall	*31*	*873*	*21345*	*9831*	*5872*	*59.7*

3.2. Grouping of mandals based on crop seasonal rainfall

Gummagatta mandal received the lowest mean crop seasonal rainfall of 278.1 mm (CV of 66.0%), while Guntakal mandal received highest mean rainfall of 436.1 mm (CV of 33.4%) over years. Among different mandals, Peddapappur mandal received the lowest crop seasonal rainfall of 61.4 mm in 2018, while D.Hirehal mandal received the highest crop seasonal rainfall of 1041.0 mm in 2020 during the study period. The descriptive statistics of crop seasonal rainfall received in mandals under 5 groups during 2001 to 2020 are given in Table 3. The groups based on rainfall were G1: < 285.3 mm, G2: 285.4 to 324.7 mm, G3: 324.8 to 403.6 mm, G4: 403.7 to 443.0 mm, and G5: > 443.1 mm. When mandals were grouped based on Mean and SD, maximum of 22 mandals were found to occur in G3 group of (Mean – SD) to (Mean + SD) viz., Rayadurg, Singanamala, Kunurpi, Kudair, Atmakur, Beluguppa, Settur, Bommanahal, Anantapur, Vajrakarur, Kanekal, Raptadu, Yellanur, Uravakonda, D.Hirehal, Pamidi, Garladinne, Yadiki, Putlur, Bukkaraya Samudram, Peddavadagur and Vidapanakal. The crop seasonal rainfall ranged from 332.8 to 403.2 mm with mean of 364.5 mm (CV of 6.2%).

Five mandals viz., Narpala, Kalyandurg, Tadipatri, Gooty and Guntakal have occurred in the G4 group of (Mean + SD) to (Mean + 2SD) with rainfall in the range of 405.9 to 436.1 mm with mean of 418.5 mm (CV of 3.2%). Three mandals have occurred in G2 group, while one mandal has occurred in G1 group. Gummigatta has occurred in 1st group with mean rainfall of 278.1 mm (CV of 66.0%), while Kambadur, Peddapappur and Brahmasamudram have occurred in the G2 group with rainfall in the range of 286.5 to 315.8 mm with mean of 299.8 mm (CV of 4.9%). Among different mandals, Peddavadagur mandal received mean crop seasonal rainfall of 391.6 mm with lowest CV of 32.0%, while Gummagatta received rainfall of 278.1 mm with highest CV of 66.0% over years. Christian and Ebenebe Izuchkwu (2009) observed similar results when rainfall distribution was analyzed in the dry season. Kumar et al., (2010) assessed long-term trends of rainfall for increasing and decreasing trends. A grouping of trends would provide the useful strategies for soil and water management, apart from crop water management under dry conditions. Sukumar et al., (2010) assessed the variability of rainfall in Coimbatore district. Based on GIS (Geographical Information System), the authors observed similar type of classification of distribution and variability of rainfall.

Table 3. Descriptive statistics of crop seasonal rainfall (23-41 SMW) in different groups of mandals (2001 to 2020)

Group	**Mandals**	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
G1: Less than (Mean – 2SD) (< 285.3 mm)	1 Mandal: Gummagatta			278.1	183.6	66.0
G2: (Mean -2SD) to (Mean - SD) (285.4 to 324.7 mm)	3 Mandals: Kambadur, Peddapappur, Brahmasamudram	286.5	315.8	299.8	14.8	4.9
G3: (Mean - SD) to (Mean + SD) (324.8 mm to 403.6 mm)	22 Mandals: Rayadurg, Singanamala, Kunurpi, Kudair, Atmakur, Beluguppa, Settur, Bommanahal, Anantapur, Vajrakarur, Kanekal, Raptadu, Yellanur, Uravakonda, D.Hirehal, Pamidi, Garladinne, Yadiki, Putlur, Bukkaraya Samudram, Peddavadagur, Vidapanakal	332.8	403.2	364.5	22.7	6.2
G4: (Mean + SD) to (Mean + 2SD) (403.7 mm to 443.0 mm)	5 Mandals: Narpala, Kalyandurg, Tadipatri, Gooty, Guntakal	405.9	436.1	418.5	13.5	3.2
G5: More than (Mean + 2 SD) (More than 443.1 mm)	NIL					
Overall	*31*	*278.1*	*436.1*	*364.1*	*39.4*	*10.8*

3.3. Grouping of mandals based on length of growing period

The 31 mandals in Anantapur district have LGP of (i) < 90 days, (ii) 91-120 days, (iii) 121-150 days, (iv) > 150 days. Kundurpi, Atmakur, Bommanahal, Bramha samudram, Kudair, Peddapappur, Vajrakarur and Rayadurg were in the group LGP < 90 days with duration range of 56-84 days and mean of 69 days (CV of 14.8%). These mandals had an onset of monsoon during 32nd to 34th SMW, while the withdrawal of monsoon was during 42nd to 45th SMW. Rapthadu, Ananthapur, Beluguppa, Bukkarayasamudram, Garladinne, Gummagatta, Kalyandurg, Kambadur, Kanekal, Narpala, Settur, Singanamala, Pamidi, Putlur, Tadipatri, Uravakonda and Yellanur have LGP of 91 to 120 days with duration range of 91 to 112 days and mean of 103 days (CV of 6.6%). These mandals had an onset of monsoon during 28th to 29th SMW, while the withdrawal of monsoon was during 42nd to 44th SMW. Guntakal, Peddavadugur, Vidapanakal, Yadiki and Gooty have LGP of 121 to 150 days with duration in the range of 133 to 140 days with mean of 139 days (CV of 2.3%). These mandals had an onset of monsoon during 23rd to 25th SMW, while the withdrawal of monsoon was during 43nd to 45th SMW. D Hirehal has LGP of more than 150 days with onset of monsoon during 23rd SMW and withdrawal of monsoon during 46th SMW with duration of 161 days.

Based on the statistical grouping with mean and standard deviation of LGP of different mandals, maximum of 20 mandals viz., Vajrakarur, Rayadurg, Kundurpi, Pamidi, Beluguppa, Bukkaraya samudram, Singanamala, Putlur, Tadipatri, Uravakonda, Yellanur, Rapthadu, Ananthapuramu, Garladinne, Narpala, Gummagatta, Kalyandurg, Kambadur, Kanekal, Settur have occurred in 3rd group of (Mean – SD) to (Mean + SD) with duration in the range of 77 to 112 days with mean of 100 days (CV of 10.9%). Five mandals viz., Bramhasamudram, Kudair, Atmakur, Bommanahal, Peddapappur have fallen in the 2nd group of (Mean – 2SD) to (Mean – SD) with duration range of 56 to 70 days with mean of 63 days (CV of 11.1%). Similarly, five mandals viz., Yadiki, Guntakal, Peddavadugur, Vidapanakal, Gooty have fallen in the 4th group of (Mean + SD) to (Mean + 2SD) with duration range of 133 to 140 days and mean of 139 days (CV of 2.3%). Only one mandal viz., D Hirehal has occurred in 5th group with duration of 161 days. The descriptive statistics of LGP, SMW of onset and withdrawal of monsoon in different mandals are given in Table 4.

Table 4. Descriptive statistics of length of growing period in different groups of mandals

Group	Mandals (LGP & SMW range)	Minimum	Maximum	Mean	SD	CV
G1: Less than (Mean – 2SD) (< 50 Days)	NIL					
G2: (Mean -2SD) to (Mean - SD) (51 to 76 Days)	5 Mandals: Bramha samudram, Kudair, Atmakur, Bommanahal, Peddapappur (*LGP: < 90 Days: Week start: 34; Week end: 42 to 44*)	56	70	63	7.0	11.1
G3: (Mean - SD) to	20 Mandals: Vajrakarur,	77	112	100	10.9	10.9

(Mean + SD) (77 to 128 Days)	Rayadurg, Kundurpi, Pamidi, Beluguppa, Bukkaraya samudram, Singanamala, Putlur, Tadipatri, Uravakonda, Yellanur, Rapthadu, Ananthapuramu, Garladinne, Narpala, Gummagatta, Kalyandurg, Kambadur, Kanekal, Settur (*LGP: 91-120 Days: Week start: 28 to 34; Week end: 42 to 45*)					
G4: (Mean + SD) to (Mean + 2SD) (129 to 154 Days)	5 Mandals: Yadiki, Guntakal, Peddavadugur, Vidapanakal, Gooty (*LGP: 121-150 Days: Week start: 23 to 25; Week end: 43 to 45*)	133	140	139	3.1	2.3
G5: More than (Mean + 2SD) (> 155 days)	1 Mandal: D Hirehal (*LGP: > 150 Days: Week start: 23; Week end: 46*)			161		
Overall	*31*	*56*	*161*	*102*	*26.1*	*25.5*

3.4. Grouping of mandals based on yield

Peddapappur mandal attained highest yield of 1993 kg/ha in 2017, while there was no yield attained in Yellanur in 2009 with mean yield of 481 kg/ha (CV of 79.5%) over all mandals and years. Among different mandals, Kambadur attained lowest yield of 283 kg/ha (CV of 104.0%), while Peddavadagur attained highest yield of 723 kg/ha (CV of 81.0%) over years. The descriptive statistics of yield attained in mandals during 2001 to 2020 are given in Table 5. The groups based on yield were G1: < 246 kg/ha, G2: 247 to 363 kg/ha, G3: 364 to 598 kg/ha, G4: 599 to 716 kg/ha, and G5: > 717 kg/ha. When mandals were grouped based on Mean and SD of yield, 7 mandals have fallen in the G2 group of (Mean -2SD) to (Mean - SD) viz., Kambadur, Kalyandurg, Kundurpi, Settur, Rapthadu, Bramhasamudram and Atmakur. Pod yields in the range of 283 to 355 kg/ha with mean of 332 kg/ha (CV of 7.4%) were attained by these 7 mandals.

Eighteen mandals have fallen in the G3 group of (Mean–SD) to (Mean+SD) group with pod yield ranging from 369 to 581 kg/ha and mean yield of 481 kg/ha (CV of 13.0%). The mandals which fell in this group are Beluguppa, Kudair, Anantapur, Narpala, Rayadurg, Kanekal, Garladinne, B.K.Samudram, Uravakonda, D.Hirehal,

Gummagatta, Yellanur, Pamidi, Vajrakarur, Singanamala, Bommanahal, Putlur and Yadiki. Five mandals viz., Tadipatri, Peddapappur, Guntakal, Vidapanakal and Gooty have fallen in the G4 group of (Mean+SD) to (Mean+2SD) with pod yield ranging from 604 to 663 kg/ha and mean of 641 kg/ha (CV of 3.5%). Peddavadagur has fallen in the G5 group of more than (Mean+2SD) with mean pod yield of 723 kg/ha (CV of 81.0%) over years. Among different mandals, Kanekal had a mean yield of 465 kg/ha with lowest CV of 46.1%, while Kambadur had a mean yield of 283 kg/ha with highest CV of 104.0% of yield over years.

Table 5. Descriptive statistics of yield attained in different groups of mandals during 2001 to 2020

Group	**Mandals**	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
G1: Less than (Mean – 2SD) (< 246 kg/ha)	NIL					
G2: (Mean -2SD) to (Mean - SD) (247 to 363 kg/ha)	7 Mandals: Kambadur, Kalyandurg, Kundurpi, Settur, Rapthadu, Bramhasamudram, Atmakur	283	355	332	24	7.4
G3: (Mean - SD) to (Mean + SD) (364 to 598 kg/ha)	18 Mandals: Beluguppa, Kudair, Anantapur, Narpala, Rayadurg, Kanekal, Garladinne, B.K.Samudram, Uravakonda, D.Hirehal, Gummagatta, Yellanur, Pamidi, Vajrakarur, Singanamala, Bommanahal, Putlur, Yadiki	369	581	481	62	13.0
G4: (Mean + SD) to (Mean + 2SD) (599 to 716 kg/ha)	5 Mandals: Tadipatri, Peddapappur, Guntakal, Vidapanakal, Gooty	604	663	641	22	3.5
G5: More than (Mean + 2SD) (> 717 kg/ha)	1 Mandal: Peddavadagur			723	586	81.0
Overall	*31*	*283*	*723*	*481*	*117*	*24.4*

3.5. Sustainability yield index

Relationships among different parameters

Based on the pooled data over years, the mean pod yield was found to have a positive correlation of 0.451 with mean crop seasonal rainfall and 0.389 with length of growing period, while it had a negative correlation of -0.539

with mean area of groundnut observed in different mandals. The crop seasonal rainfall was found to have a positive correlation of 0.523 with LGP, while it had a negative correlation of -0.156 with area. Similarly, length of growing period was found to have a negative correlation of -0.088 with area of groundnut over years. The relationships of mean pod yield with mean crop seasonal rainfall, length of growing period and mean area of groundnut over years in different mandals are depicted in Figure 1.

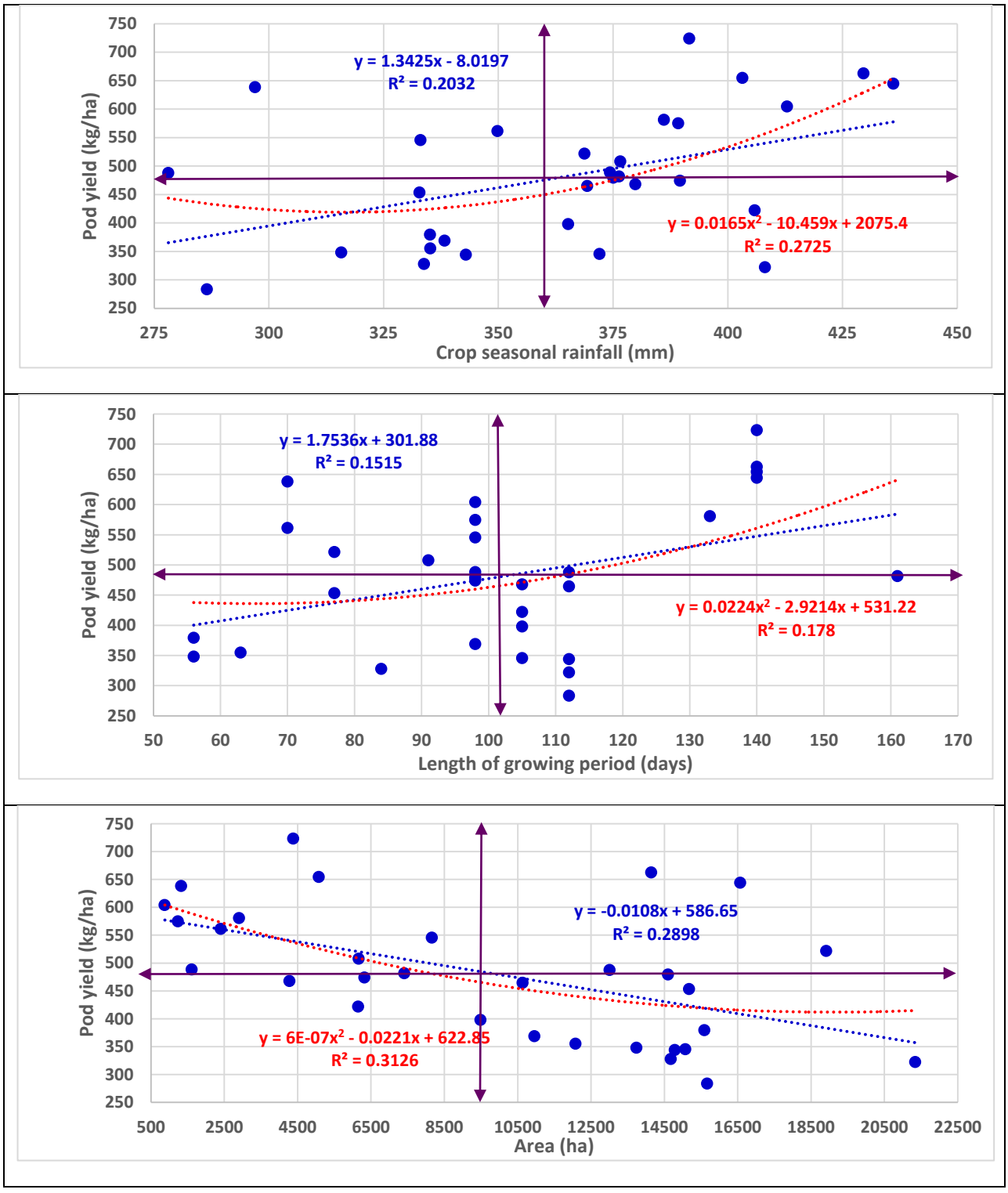

Figure 1. Relationship of pod yield with crop seasonal rainfall, length of growing period and area of groundnut in different mandals of Anantapur

The crop seasonal rainfall was found to positively influence the pod yield in different mandals during the studied period. The linear model of yield gave predictability of 0.2032, while the quadratic model of yield gave predictability of 0.2725 through crop seasonal rainfall received in different mandals over years. This indicated that the yield has increased with an increase in the crop seasonal rainfall in different years. The linear regression model of yield through length of growing period gave predictability of 0.1515, while the quadratic model gave predictability of 0.1780 in different mandals over years. This indicated that with an increase in the LGP, higher yields of groundnut were attained in different mandals with a positive rate of change in yield in different years.

Similarly, the linear regression model of yield gave predictability of 0.2898, while the quadratic model gave predictability of 0.3126 for predicting yield through the mean area of groundnut observed in different years. The area was having a negative influence on the pod yield attained in different mandals during the study period. This indicated that with an increase in the area, the pod yields have decreased in different years. Thus there is a need of growing groundnut in an optimum area in any mandal which has an ideal length of growing period and crop seasonal rainfall for attaining maximum yields. When the mean crop seasonal rainfall was less than 364 mm, the pod yield attained over years was less than the mean yield of 481 kg/ha in 8 mandals compared to more than the mean yield in 4 mandals. The pod yield was found to be less than the mean yield of 481 kg/ha in 7 mandals and more than the mean yield in 12 mandals when the crop seasonal rainfall was more than the mean of 364 mm over years. When the area of groundnut was less than the mean area of 9831 ha, the pod yield was found to be less than the mean yield of 481 kg/ha in 5 mandals compared to more than the mean yield in 10 mandals. Similarly, when the area of groundnut was more than the mean area of 9831 ha, the pod yield was found to be less than the mean yield of 481 kg/ha in 12 mandals compared to more than the mean yield in 4 mandals.

The relationships of mean crop seasonal rainfall with length of growing period and mean area of groundnut over years in different mandals are depicted in Figure 2. The crop seasonal rainfall was found to positively influence the length of growing period in different mandals during the study period. The linear model of length of growing period gave predictability of 0.2736, while the quadratic model gave predictability of 0.3696 through the crop seasonal rainfall received in different mandals received in different years. The model indicated that the length of growing period has increased with an increase in the mean crop seasonal rainfall received in different mandals over years. The linear model of area of groundnut through the crop seasonal rainfall gave predictability of 0.0244, while the quadratic model gave predictability of 0.0520 in different mandals over years. The negative relationship between area of groundnut and crop seasonal rainfall indicated that lower mean area of groundnut was observed in mandals with relatively higher mean crop seasonal rainfall compared to higher mean area in mandals with lower mean crop seasonal rainfall over years. When the mean crop seasonal rainfall was less than 364 mm, 9 mandals were found to have less than mean LGP of 102 days compared to 3 mandals with more than the mean LGP. When the mean crop seasonal rainfall was more than 364 mm, 7 mandals had mean LGP of less than 102 days compared to 12 mandals with more than the mean LGP. When the mean crop seasonal rainfall was less than 364 mm, 3 mandals were found to have less than the mean groundnut area of 9831 ha compared to 9 mandals with more than the mean area. When the mean crop seasonal rainfall was more than 364 mm, 12 mandals were found to have less than the mean area of 9831 ha compared to 7 mandals with more than the mean area over years.

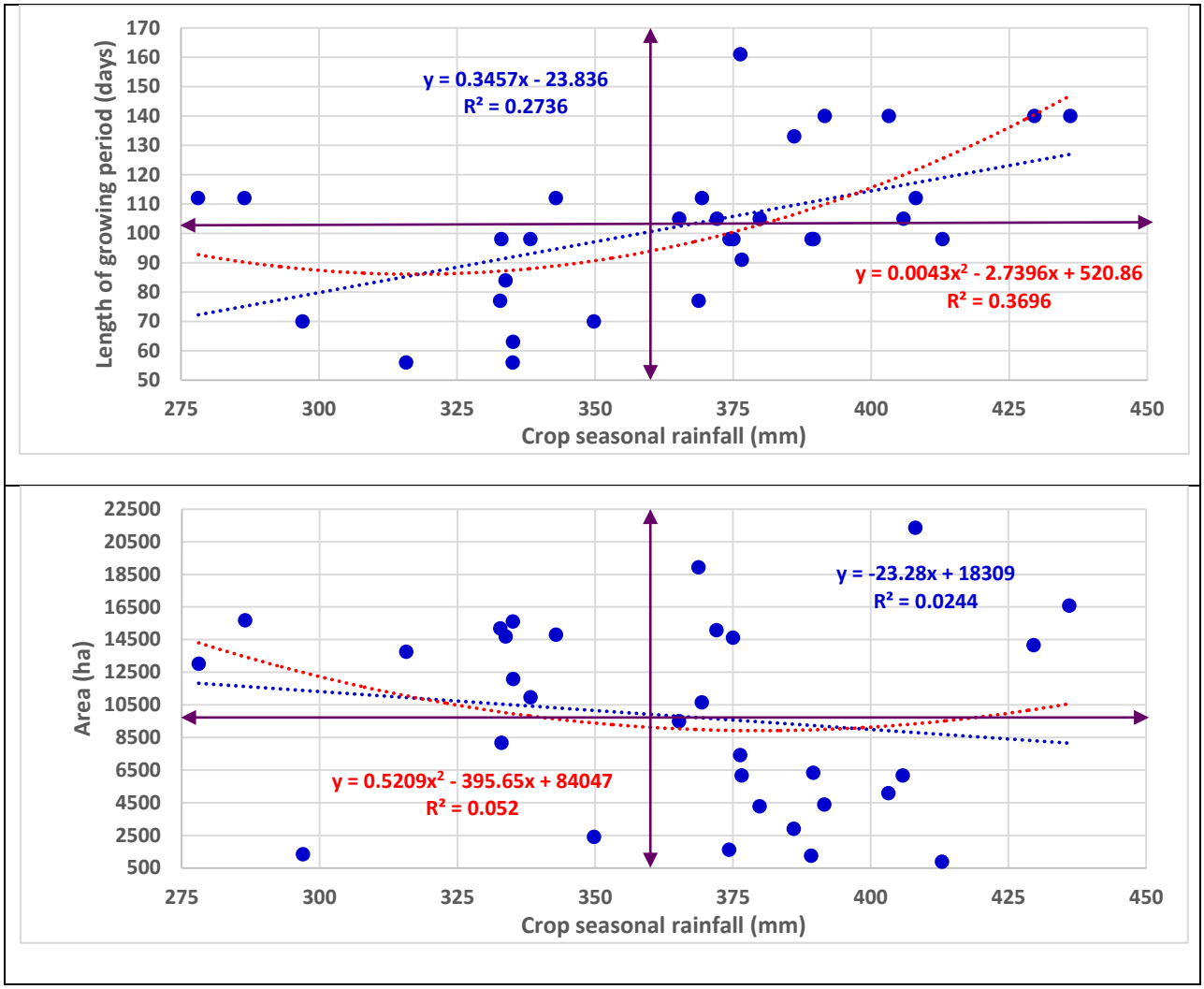

Figure 2. Relationship of length of growing period and area of groundnut with crop seasonal rainfall received in different mandals of Anantapur

The relationship of mean area of groundnut with length of growing period observed in different mandals is depicted in Figure 3.

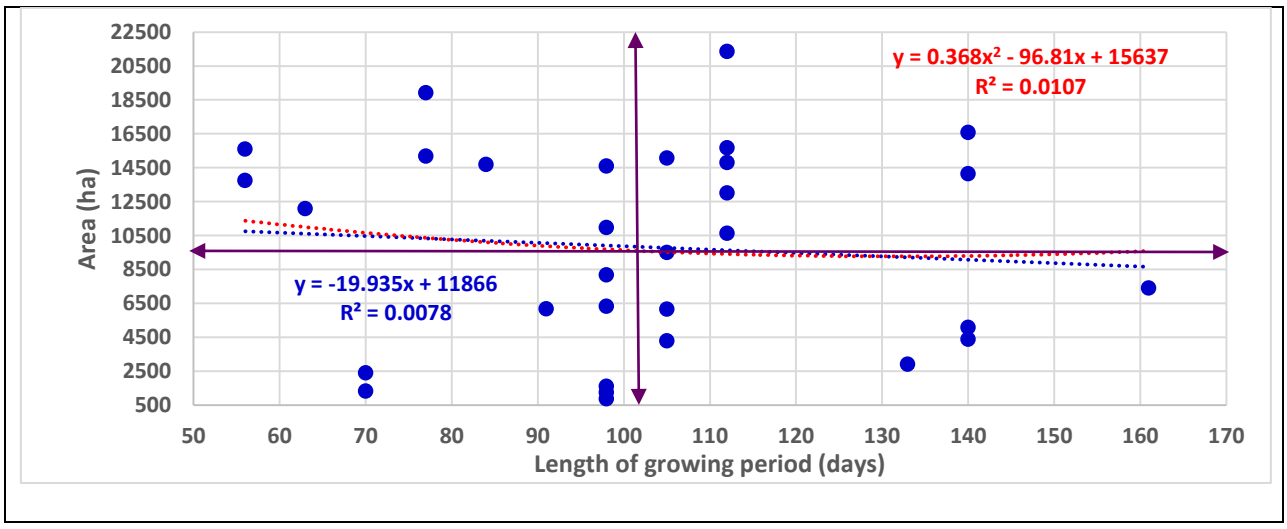

Figure 3. Relationship of area of groundnut with length of growing period in different mandals of Anantapur

The linear model of changes in area through LGP gave predictability of 0.0078, while the quadratic model gave predictability of 0.0107 over years. Among 31 mandals when the LGP is less than 102 days, 8 mandals had an area of more than the mean area of 9831 ha, compared to an equal number of mandals with less than 9831 ha. Similarly, when the LGP was more than 102 days, 8 mandals had an area of more than 9831 ha, while 7 mandals had less than 9831 ha over years.

Effect of crop seasonal rainfall on pod yield attained in different mandals

The effects of crop seasonal rainfall on pod yield attained during 2001 to 2020 were assessed based on a regression model of yield as a function of rainfall received in different years. Estimates of intercept and slope, along with R^2 and SEM (Standard Error Mean) of each mandal are given in Table 6. Significant correlation was observed between pod yield and crop seasonal rainfall in different mandals. The correlation coefficients between pod yield and crop seasonal rainfall observed in different years were found to range from 0.433 at Kalyandurg to 0.765 at Putlur. The crop seasonal rainfall was found to significantly influence the pod yield attained in different mandals as indicated by the significant regression coefficients in of crop seasonal rainfall in different mandals. The regression coefficients of crop seasonal rainfall ranged from 0.646 kg/mm at Kalyandurg to 2.297 kg/mm at Peddavadagur mandal. The prediction error based on the regression model of yield through the crop seasonal rainfall ranged from a minimum of 207.2 kg/ha at Anantapur to a maximum of 524.0 kg/ha at Peddavadagur mandal.

The regression model of yield through crop seasonal rainfall indicated significant predictability of yield at $p < 0.01$ level of significance at Putlur (0.586**), followed by Anantapur (0.549**), Singanamala (0.521**), Yellanur (0.516**), Rapthadu (0.513**), Kudair (0.413**), Tadipatri (0.381**), Atmakur (0.379**), Pamidi (0.339**). The significance of predictability of yield was at $p < 0.05$ level of significance at Brahmasamudram (0.254*), followed by BK Samudram (0.246*), Peddavadagur (0.242*), Gooty (0.227*), Yadiki (0.223*), Vajrakarur (0.212*), Guntakal (0.195*) and Kalyandurg (0.188*). Maruthi Sankar et al., observed similar results on the effects of rainfall and fertilizer on cotton yield based on long-term experiments conducted under semi-arid Vertisols. Rao et al., (2011) assessed about the long-term rainfall trends at micro and macro-level in Andhra Pradesh. They observed similar trends of rainfall over years at micro-level in the state. Sinha Anil (2001) discussed about some useful strategies for disaster management in India. Venkatachalapathi et al., (2012) assessed about the rainfall characteristics of Anantapur district. The authors observed similar trends of rainfall in the rain shadow region in the state. In a paper by Parmar et al., (2017), the authors have studied about the inter-relationships between rainfall and yield of groundnut attained in different years for assessing the changes in yield over years. They found a significant relationship and an effect of rainfall on yield over years.

Effect of area on pod yield attained in different mandals

The effects of area of groundnut on pod yield attained during 2009 to 2020 were assessed based on a regression model of yield as a function of area of groundnut observed in different years. The estimates of intercept and slope, along with R^2 and prediction error of each mandal are given in Table 6. Out of 31 mandals, significant correlation was observed between pod yield and area of groundnut only in 3 mandals viz., Kalyandurg (-0.764), followed by Brahmasamudram (-0.674) and Rapthadu (-0.584). The area of groundnut was found to significantly influence the pod yield attained in these 3 mandals as indicated by the significant regression coefficients of the area of groundnut

in different mandals with magnitudes of -0.021 kg/ha at Kalyandurg, -0.047 kg/ha at Brahmasamudram and -0.049 kg/ha at Rapthadu. Among the mandals with significant predictability of yield through area of groundnut, Kalyandurg had minimum prediction error of 137.5 kg/ha, while Brahmasamudram had a prediction error of 141.5 kg/ha compared to the maximum prediction error of 169.3 kg/ha among these 3 mandals. Srinivasan et al., (2020) studied about the changes in groundnut area, apart from the suitability of land for growing groundnut under arid environment of Andhra Pradesh. Based on the effects of changes in area and their influence on groundnut pod yield in different mandals observed in our study, we have identified superior mandals for enhancing the area of groundnut and attain significantly higher production of groundnut under arid conditions.

Table 6. Mandal-wise regression models of yield through crop seasonal rainfall and area of groundnut in Anantapur

Mandals	**r-value**	**Regression model**	**R^2**	**PE**	**r-value**	**Regression model**	**R^2**	**PE**
Anantapur	0.741	Y = -133.732 + 1.455** (RF)	0.549**	207.2	-0.040	Y = 410.578 – 0.004 (A)	0.002	246.8
Atmakur	0.615	Y = -84.638 + 1.312** (RF)	0.379**	234.0	-0.073	Y = 408.883 – 0.007 (A)	0.010	301.1
B.K.Samudram	0.495	Y = 81.128 + 1.008* (RF)	0.246*	332.8	-0.266	Y = 690.503* - 0.033 (A)	0.071	381.4
Beluguppa	0.257	Y = 186.737 + 0.538 (RF)	0.066	355.25	-0.600	Y = 636.592** - 0.026 (A)	0.360*	221.3
Bommanahal	0.164	Y = 454.673* + 0.305 (RF)	0.027	354.7	-0.253	Y = 671.363** - 0.066 (A)	0.064	293.4
Bramh samudram	0.504	Y = 66.626 + 0.891* (RF)	0.254*	247.1	-0.674	Y = 927.825** - 0.047* (A)	0.454*	141.5
D.Hirehal	0.295	Y = 299.132 + 0.484 (RF)	0.087	351.2	-0.243	Y = 555.023** - 0.019 (A)	0.059	238.0
Garladinne	0.423	Y = 133.577 + 0.879 (RF)	0.179	285.9	-0.431	Y = 647.654** - 0.052 (A)	0.186	275.8
Gooty	0.477	Y = 147.480 + 1.199* (RF)	0.227*	413.5	-0.320	Y = 1471.385 – 0.063 (A)	0.103	404.1
Gummagatta	0.229	Y = 349.432* + 0.496 (RF)	0.053	397.3	-0.256	Y = 807.110 – 0.035 (A)	0.065	250.5
Guntakal	0.441	Y = 40.408 + 1.385* (RF)	0.195*	421.2	0.247	Y = 87.277 + 0.025 (A)	0.061	289.3

Kalyandurg	0.433	Y = 58.136 + 0.646* (RF)	0.188*	275.4	-0.764	Y = 693.658** - 0.021** (A)	0.584**	137.5
Kambadur	0.353	Y = 93.886 + 0.661 (RF)	0.125	283.1	-0.827	Y = 833.877** - 0.036** (A)	0.683**	180.5
Kanekal	-0.09	Y = 507.551** - 0.116 (RF)	0.010	219.1	-0.131	Y = 526.821** - 0.006 (A)	0.017	190.6
Kudair	0.642	Y = -64.938 + 1.326** (RF)	0.413**	238.4	-0.281	Y = 621.290 – 0.020 (A)	0.079	222.1
Kundurpi	0.162	Y = 207.731 + 0.359 (RF)	0.026	270.8	-0.926	Y = 817.285** - 0.039** (A)	0.858**	104.6
Narpala	0.409	Y = 197.491 + 0.634 (RF)	0.167	359.3	-0.727	Y = 805.012** - 0.070* (A)	0.529**	262.8
Pamidi	0.582	Y = -84.812 + 1.573** (RF)	0.339**	368.5	-0.287	Y = 689.151 – 0.047 (A)	0.082	327.3
Peddapappur	0.290	Y = 309.786 + 1.105 (RF)	0.084	540.6	-0.033	Y = 581.025 – 0.018 (A)	0.001	538.7
Peddavadagur	0.492	Y = -176.073 + 2.297* (RF)	0.242*	524.0	-0.482	Y = 984.742** - 0.077 (A)	0.232	473.1
Putlur	0.765	Y = -296.070 + 2.237** (RF)	0.586**	291.3	-0.084	Y = 561.887** - 0.020 (A)	0.007	439.1
Rapthadu	0.716	Y = -123.346 + 1.260** (RF)	0.513**	211.0	-0.584	Y = 1049.653** - 0.049* (A)	0.341*	169.3
Rayadurg	0.311	Y = 217.388 + 0.625 (RF)	0.07	253.9	-0.319	Y = 848.271 – 0.031 (A)	0.102	232.7
Settur	0.165	Y = 239.235 + 0.355 (RF)	0.027	346.8	-0.664	Y = 635.625** - 0.024* (A)	0.441*	162.3
Singanamala	0.722	Y = -41.171 + 1.843** (RF)	0.521**	304.3	-0.423	Y = 887.698* - 0.052 (A)	0.179	324.2
Tadipatri	0.618	Y = -76.322 + 1.648** (RF)	0.381**	338.7	-0.176	Y = 631.428** - 0.055 (A)	0.031	398.7
Uravakonda	0.284	Y = 284.151 + 0.520 (RF)	0.081	347.4	-0.661	Y = 1008.882** - 0.043* (A)	0.436*	157.0

Vajrakarur	0.461	Y = 159.284 + 0.982* (RF)	0.212*	341.1	-0.340	Y = 837.537* - 0.021 (A)	0.116	286.3
Vidapanakal	0.093	Y = 590.614** + 0.158 (RF)	0.010	331.2	0.019	Y = 625.244* + 0.003 (A)	0.001	259.6
Yadiki	0.472	Y = -43.195 + 1.616* (RF)	0.223*	414.0	-0.137	Y = 591.884** - 0.023 (A)	0.019	419.9
Yellanur	0.719	Y = -19.021 + 1.355** (RF)	0.516**	236.8	-0.161	Y = 550.176** - 0.029 (A)	0.026	338.9

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level respectively Y : Yield (kg/ha) A: Area (ha)

RF : Crop seasonal rainfall (mm) R^2 : Coefficient of determination PE: Prediction error (kg/ha)

Regression model of yield through area, rainfall and LGP

In order to assess the sustainability of groundnut pod yield in different mandals, a multivariate regression model of yield through area, crop seasonal rainfall and length of growing period using observations of 31 mandals was calibrated. The model is useful to assess the (i) effects of variables on yield, and (ii) predictability of yield attained in different mandals. The groundnut area was found to have a significant negative effect on yield with a rate of change of -0.01 kg/ha, while the crop seasonal rainfall and LGP had a non-significant positive effect of 0.80 kg/mm and 0.93/day on yield respectively. The model gave a significant coefficient of determination of 0.46 with prediction error of 90.9 kg/ha. The regression model of different mandals over years is,

$$Y = 188.748 + 0.80\ (CRF) + 0.93\ (LGP) - 0.01^{**}\ (Area) \qquad (8)$$

Using the (i) mean pod yield attained in each mandal, (ii) maximum mean pod yield of 723 kg/ha attained in Peddapappur mandal over years, and (iii) prediction error of 90.9 kg/ha based on the multivariate regression model of yield through area, crop seasonal rainfall and LGP parameters, the sustainability yield index (SYI) of each mandal has been derived. The SYI of different mandals ranged from 26.6% to 87.5% with mean of 53.9% (CV of 30.1%) over years. Among different mandals, Kambadur was found to have the lowest SYI of 26.6%, while Peddavadagur had the highest SYI of 87.5% for groundnut over years.

Grouping of mandals based on sustainability yield index

The descriptive statistics of SYI attained under 5 groups of mandals are given in Table 7. The groups based on SYI were G1: < 15.4%, G2: 15.4% to 32.6%, G3: 32.7% to 66.8%, G4: 66.9% to 84.0%, and G5: > 84.1%. When mandals were grouped based on Mean and SD of SYI, 7 mandals have fallen in the G2 group of (Mean–2SD) to (Mean–SD) viz., Kambadur, Kalyandurg, Kundurpi, Settur, Rapthadu, Bramhasamudram and Atmakur with SYI ranging from 26.6% to 36.5% with mean of 33.4% (CV of 10.1%) over years. Eighteen mandals have fallen in the G3 group of (Mean–SD) to (Mean+SD) viz., Beluguppa, Kudair, Anantapur, Narpala, Rayadurg, Kanekal, Garladinne, B.K.Samudram, Uravakonda, D.Hirehal, Gummagatta, Yellanur, Pamidi, Vajrakarur, Singanamala, Bommanahal, Putlur and Yadiki with SYI ranging from 38.4% to 67.8% with mean of 53.9% (CV of 16.0%). Five

mandals viz., Tadipatri, Peddapappur, Guntakal, Vidapanakal and Gooty were found to fall in the G4 group of (Mean+SD) to (Mean+2SD) with SYI in the range of 71.0% to 79.1% with mean of 76.0% (CV of 4.1%). Peddavadagur has fallen in the 5th group of more than (Mean + 2SD) with maximum SYI of 87.5%. Our findings are in agreement with the findings made by Vijaya Kumar et al., (2019) who described about a new index for grouping of drought prone areas in Andhra Pradesh.

Table 7. Descriptive statistics of sustainability yield index of groundnut in different groups of mandals during 2001 to 2020

Group	**Mandals**	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
G1: Less than (Mean – 2SD) (SYI < 15.4%)	NIL					
G2: (Mean -2SD) to (Mean - SD) (SYI: 15.4% to 32.6%)	7 Mandals: Kambadur, Kalyandurg, Kundurpi, Settur, Rapthadu, Bramhasamudram, Atmakur	26.6	36.5	33.4	3.4	10.1
G3: (Mean - SD) to (Mean + SD) (SYI: 32.7% to 66.8%)	18 Mandals: Beluguppa, Kudair, Anantapur, Narpala, Rayadurg, Kanekal, Garladinne, B.K.Samudram, Uravakonda, D.Hirehal, Gummagatta, Yellanur, Pamidi, Vajrakarur, Singanamala, Bommanahal, Putlur, Yadiki	38.4	67.8	53.9	8.6	16.0
G4: (Mean + SD) to (Mean + 2SD) (SYI: 66.9% to 84.0%)	5 Mandals: Tadipatri, Peddapappur, Guntakal, Vidapanakal, Gooty	71.0	79.1	76.0	3.1	4.1
G5: More than (Mean + 2SD) (SYI > 84.1%)	1 Mandal: Peddavadagur			87.5		
Overall	*31*	*26.6*	*87.5*	*53.9*	*16.2*	*30.1*

Testing differences of parameters between different groups

Based on the Student's t-test, the differences between mean values of groundnut area (ha), crop seasonal rainfall (mm), LGP (days), yield (kg/ha) and SYI (%) of different pairs of groups were tested. The number of mandals, mean and standard deviation of different pairs of groups of mandals along with the t-calculated values for making a comparison with the t-critical values at $p < 0.05$ and $p < 0.01$ levels of significance are given in Table 8. Significant

differences in the mean groundnut area were found to exist between (i) G2 and G3, (ii) G2 and G4, (iii) G2 and OA, (iv) G3 and G4, and (v) G4 and OA groups of mandals. The mandals grouped under G3 (10799 ha), G4 (18944 ha) and overall (9831 ha) groups were superior to G2 (1724 ha) with significantly higher mean groundnut area; while G4 (18944 ha) was significantly superior to G3 (10799 ha) and overall (9831 ha) groups for the mean area of mandals. G3 (10799 ha) and OA (9831 ha) groups were at par with each other for the mean area of mandals observed over years. Significant differences in the mean crop seasonal rainfall were found to exist between (i) G2 and G3, (ii) G2 and G4, (iii) G2 and OA, (iv) G3 and G4, and (v) G4 and OA groups of mandals. The mandals grouped under G3 (364.5 mm), G4 (418.5 mm) and overall (364.1 mm) groups were superior to G2 (299.8 mm) with significantly higher mean crop seasonal rainfall; while G4 (418.5 mm) was superior to G3 (364.5 mm) and overall (364.1 mm) for the mean crop seasonal rainfall received by mandals. G3 (364.5 mm) and overall (364.1 mm) groups were at par with each other for the crop seasonal rainfall received over years.

Significant differences in the mean LGP were found to exist between (i) G2 and G3, (ii) G2 and G4, (iii) G2 and OA, (iv) G3 and G4, and (v) G4 and OA groups of mandals. The mandals under G3 (100 days), G4 (139 days) and overall (102 days) groups were found to be superior to G2 (63 days) with significantly higher length of growing period; while G4 (139 days) was superior to G3 (100 days) and overall (102 days) for the mean LGP observed in different mandals. G3 (100 days) and overall (102 days) groups were found to be at par with each other for the mean LGP observed in different mandals. Significant differences in the mean pod yield were found to exist between (i) G2 and G3, (ii) G2 and G4, (iii) G2 and OA, (iv) G3 and G4, and (v) G4 and OA groups of mandals. The mandals under G3 (481 kg/ha), G4 (641 kg/ha) and overall (481 kg/ha) groups were superior to G2 (332 kg/ha) with significantly higher mean pod yield; while G4 was superior to G3 and overall for the mean pod yield attained in different mandals. G3 (481 kg/ha) and overall (481 kg/ha) groups were at par with each other for the mean pod yield attained in the mandals over years. Significant differences in the mean SYI (%) values were found to exist between (i) G2 and G3, (ii) G2 and G4, (iii) G2 and OA, (iv) G3 and G4, and (v) G4 and OA groups of mandals. The mandals under G3 (53.9%), G4 (76.0%) and overall (53.9%) groups were found to be superior with significantly higher SYI compared to G2 (33.4%); while G4 (76.0%) was superior to G3 (33.4%) and overall (33.4%) groups for the mean SYI (%) attained in different mandals. G3 (33.4%) and overall (33.4%) groups were at par with each other for the mean SYI attained in different mandals over years.

Table 8. Testing the differences of groundnut area, crop seasonal rainfall, length of growing period, pod yield and sustainability yield index between pairs of groups of mandals of Anantapur

Groups	**First group of mandals**			**Second group of mandals**			**t-cal**	**Dof**	**t-cri**	**t-cri**
	Mandals	**Mean**	**SD**	**Mandals**	**Mean**	**SD**			**p<0.05**	**p<0.01**
Area (ha)										
G2 vs G3	6	1724	772	22	10799	4116	-5.305**	26	2.056	2.779
G2 vs G4	6	1724	772	3	18944	2388	-16.988**	7	2.365	3.499
G2 vs OA	6	1724	772	31	9831	5872	-3.339**	35	2.031	2.727

G3 vs G4	22	10799	4116	3	18944	2388	-3.312**	23	2.069	2.807
G3 vs OA	22	10799	4116	31	9831	5872	0.665	51	2.010	2.682
G4 vs OA	3	18944	2388	31	9831	5872	2.636*	32	2.042	2.750
Crop seasonal rainfall (mm)										
G2 vs G3	3	299.8	14.8	22	364.5	22.7	-4.751**	23	2.069	2.807
G2 vs G4	3	299.8	14.8	5	418.5	13.5	-11.654**	6	2.447	3.707
G2 vs OA	3	299.8	14.8	31	364.1	39.4	-2.775**	32	2.042	2.750
G3 vs G4	22	364.5	22.7	5	418.5	13.5	-5.071**	25	2.060	2.787
G3 vs OA	22	364.5	22.7	31	364.1	39.4	0.043	51	2.010	2.682
G4 vs OA	5	418.5	13.5	31	364.1	39.4	3.026**	34	2.031	2.727
Length of growing period (days)										
G2 vs G3	5	63	7	20	100	10.9	-7.165**	23	2.069	2.807
G2 vs G4	5	63	7	5	139	3.1	-22.198**	8	2.306	3.355
G2 vs OA	5	63	7	31	102	26.1	-3.285**	34	2.031	2.727
G3 vs G4	20	100	10.9	5	139	3.1	-7.807**	23	2.069	2.807
G3 vs OA	20	100	10.9	31	102	26.1	-0.324	49	2.010	2.682
G4 vs OA	5	139	3.1	31	102	26.1	3.129**	34	2.031	2.727
Pod yield (kg/ha)										
G2 vs G3	7	332	24	18	481	62	-6.116**	23	2.069	2.807
G2 vs G4	7	332	24	5	641	22	-22.726**	10	2.228	3.169
G2 vs OA	7	332	24	31	481	117	-3.320**	36	2.031	2.727
G3 vs G4	18	481	62	5	641	22	-5.592**	21	2.080	2.831
G3 vs OA	18	481	62	31	481	117	0.000	47	2.010	2.682
G4 vs OA	5	641	22	31	481	117	3.014**	34	2.031	2.727
Sustainability yield index (%)										
G2 vs G3	7	33.4	3.4	18	53.9	8.6	-6.060**	23	2.069	2.807
G2 vs G4	7	33.4	3.4	5	76.0	3.1	-22.159**	10	2.228	3.169
G2 vs OA	7	33.4	3.4	31	53.9	16.2	-3.298**	36	2.031	2.727
G3 vs G4	18	53.9	8.6	5	76.0	3.1	-5.565**	21	2.080	2.831
G3 vs OA	18	53.9	8.6	31	53.9	16.2	0.000	47	2.010	2.682
G4 vs OA	5	76.0	3.1	31	53.9	16.2	3.006**	34	2.031	2.727

* and ** indicate significance at p< 0.05 and p<0.01 level respectively OA: Over all

Dof: Degrees of freedom SD: Standard deviation t-cal: t-calculated t-cri: t-critical

Ranking of different mandals for superiority

Ranks were assigned to the parameters under different categories viz., (i) RS1: mean values of yield (kg/ha), crop seasonal rainfall (mm), area (ha) and LGP (days); (ii) RS2: coefficient of variation (%) of yield, area and crop seasonal rainfall; and (iii) RS3: sustainability yield index (%) derived for different mandals. Using RS1, RS2 and RS3 values, rank sums of different mandals were derived and are depicted in Figure 4. Among 31 mandals, Guntakal was found to be superior with the lowest rank sum of 30, while Kambadur attained the highest rank sum of 176. Guntakal, Gooty and Vidapanakal were found to be the top 3 mandals with rank sums of 30, 38 and 70 respectively. Guntakal was superior with 1st rank for the mean crop seasonal rainfall, 2nd rank for the LGP, 3rd rank for the mean area, 4th rank for the mean yield and SYI, and 2nd rank for the coefficient of variation of crop seasonal rainfall over years. Gooty was the 2nd best mandal by attaining 2nd rank for the mean crop seasonal rainfall, LGP, mean yield, SYI and CV of area over years. Vidapanakal was the 3rd best mandal with 2nd rank for LGP and CV of yield, and 3rd rank for yield and SYI. A few mandals which were superior based on the CV as indicated by lower RS2 values, they were inferior due to higher RS1 and RS3 values. Thus Guntakal mandal was superior with mean groundnut area of 16570 ha (17.3%), crop seasonal rainfall of 436.1 mm (CV of 33.4%), LGP of 140 days, pod yield of 644 kg/ha (CV of 70.9%) and SYI of 76.5% compared to other mandals. Gooty was the 2nd best mandal with mean groundnut area of 14146 ha (CV of 14.6%), crop seasonal rainfall of 429.6 mm (CV of 42.4%), LGP of 140 days, pod yield of 663 kg/ha (CV of 69.1%) and SYI of 79.1%. Similarly, Vidapanakal was the 3rd best mandal with mean groundnut area of 5077 ha (CV of 31.1%), crop seasonal rainfall of 403.2 mm (CV of 47.4%), LGP of 140 days, pod yield of 654 kg/ha (CV of 49.5%) and SYI of 77.9%. The pod yields and SYI values were found to be higher in these 3 mandals due to better crop seasonal rainfall condition and length of growing period. Accordingly, the farmers could enhance the area of groundnut in these 3 superior mandals for sustaining higher yields over years.

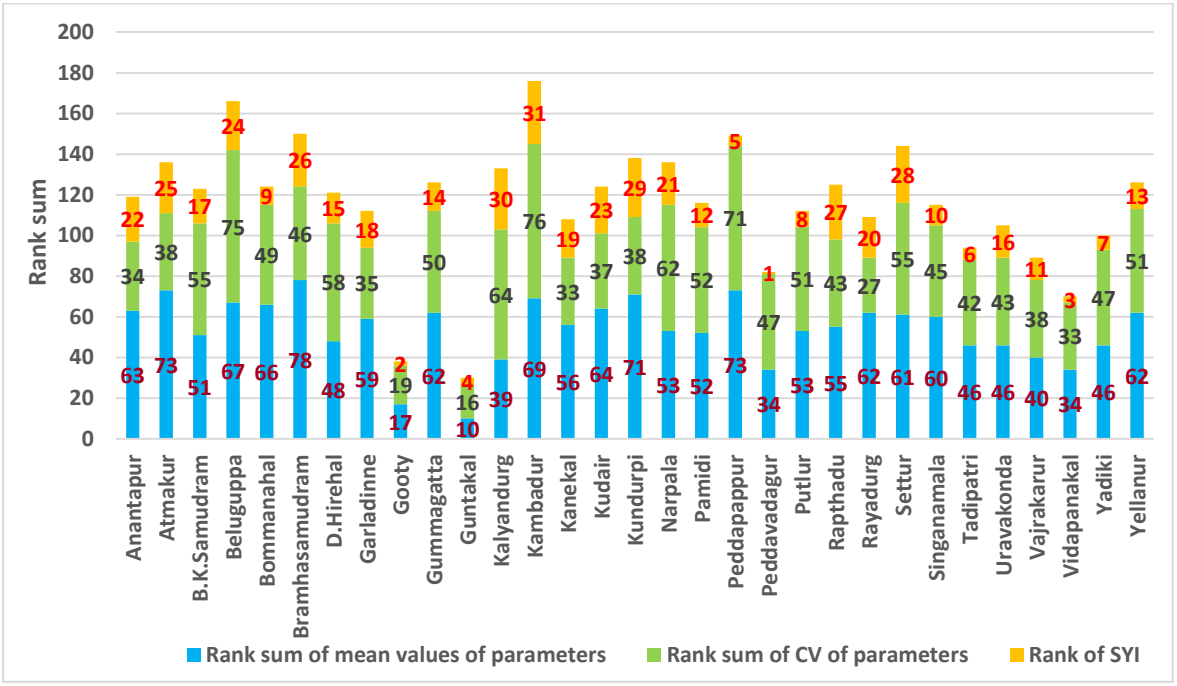

Figure 4. Ranking of mandals for mean and variation of crop seasonal rainfall, LGP, area, pod yield and SYI of groundnut in Anantapur

4. Summary

An assessment has been made to identify superior mandals out of 31 mandals of Anantapur district using observations collected on groundnut area (ha) during 2009 to 2020, crop seasonal rainfall (mm) and yield (kg/ha) during 2001 to 2020 and LGP of each mandal. Statistical grouping of mandals into 5 groups has been made based on the mean and standard deviation (SD) of each parameter, viz., (i) G1: Less than (Mean – 2SD); (ii) G2: (Mean – 2SD) to (Mean – SD); (iii) G3: (Mean – SD) to (Mean + SD); (iv) G4: (Mean + SD) to (Mean + 2SD); and (v) G5: More than (Mean + 2SD). Maximum of 22 mandals for area and crop seasonal rainfall, 20 mandals for LGP and 18 mandals for yield have fallen in the group G3. Estimates of correlation were derived between groundnut area, crop seasonal rainfall and yield for each mandal over years and tested for significance to assess the superiority of mandals. The correlation coefficients of yield and crop seasonal rainfall were found to be significant and ranged from 0.433 at Kalyandurg to 0.765 at Putlur. Significant correlation between yield and area of groundnut was observed in Kalyandurg (-0.764), Brahmasamudram (-0.674) and Rapthadu (-0.584). The predictability of yield and prediction error was derived based on a regression model of yield calibrated through the crop seasonal rainfall, LGP and area of groundnut of different mandals. The model gave significant predictability (R^2) value of 0.46 with prediction error of 90.9 kg/ha. The SYI (Sustainability Yield Index) of mandals ranged from 26.6% to 87.5% with mean of 53.9% (CV of 30.1%) over years. Kambadur had the lowest SYI of 26.6%, while Peddavadagur had the highest SYI of 87.5% for sustaining groundnut yield over years. Ranks were assigned to the mean and coefficient of variation of area of groundnut, crop seasonal rainfall and yield, LGP and SYI of each mandal and rank sums were derived for identifying superior mandals. Among different mandals, Guntakal, Gooty and Vidapanakal were superior mandals with rank sums of 30, 38 and 70 respectively. The pod yields were highly sustainable in these mandals due to higher LGP and crop seasonal rainfall. We recommend that the farmers of these mandals could enhance the area of groundnut and sustain maximum yields under arid Alfisols.

Declarations

Source of Funding

This research work did not receive any grant from funding agencies in the public or not-for-profit sectors.

Competing Interests Statement

Authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this research work.

Authors' Contributions

All authors equally contributed to research and paper drafting.

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